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Negative uniaxial films from lyotropic liquid crystalline material for liquid crystal display applications

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For a certain class of molecules which form a lyotropic liquid crystalline phase, the oriented molecular layers possess negative birefringence. When the liquid crystal is sheared onto a substrate to produce a thin film, the optic axis orients along the shearing direction of the material. The dried lyotropic films can be applied for improvement of the viewing angle performance of liquid crystal displays.

1. Introduction

Although nematic liquid crystal displays (LCDs) (e.g. twisted nematics, bend cells) have enjoyed great success over other types of LCDs, their introduction into certain high volume applications, such as large area desktop monitors, has suffered as a result of their poor viewing cone. The poor viewing angle performance and image inversion of the LCD is due to the positive birefringence of the LC layer incorporated between two polarizers. This residual birefringence produces undesirable light leakage for off-normal viewing in display modes that use two crossed polarizers in the dark state. The idea of optical compensation using passive birefringent films was developed in order to overcome this shortcoming. The ideal compensation film for producing a good dark state has negative birefringence and an optic axis that mirrors that of the LC layer. Negative birefringence films with the optic axis perpendicular to the film surface (C-plates) [1] and discotic layers with splayed distribution of the optic axis [2] improve the optical performance of several display modes [2, 3]. However, compensation of modes having planar orientation of the LC molecules in the dark state requires a negative film, with the optic axis in the plane (A-plate). In our previous studies [4, 5] we have shown the possible applications of negative A-plates for the compensation of twisted nematic displays operating in normally black and normally white modes. Typically, negative A-plates are formed by the stretching of polymer films, a process that is awkward and has limitations on the lower limit of the birefringence that can be achieved (> 70 nm). In this paper, we describe a new lyotropic discotic film for the fabrication of negative A-plates that overcomes these drawbacks. We also show its benefits for the compensation of a twisted nematic display in combination with the splayed discotic films manufactured by Fuji Co.

Discotic LCs [6] feature flat disc-like or plank-like molecules that form columnar and nematic phases with negative birefringence. A lower refractive index is observed for the extraordinary wave polarized perpendicular to the plane of the discs: $n_e < n_o$, where n_e and n_o are the refractive indices for the extraordinary and ordinary wave, respectively. The relatively low value of the birefringence of the discotics [7] $n_o - n_e = 0.05$, high mesophase temperatures and difficulty in aligning the discs [8] restrict the applications of the thermotropic discotics. However, lyotropic discotics are very attractive for various applications because of their high birefringence and room temperature processing capabilities.

2. Optical properties of the lyotropic discotic film

Negative birefringence films studied in this work were made from a water mixture of plank-like dye molecules introduced by Optiva Inc.† The molecules of the compound have a polyaromatic rigid core and a hydrophilic ionic solubilizing group at the periphery, and are similar to molecules described in [9]. The molecules have conjugated electrons in the plane of the core. Because of the hydrophilic properties of the periphery of the molecule they assemble into stacks with degenerate molecule orientation in the molecular plane. The resultant phase is uniaxial with the lower refractive index along the director and higher refractive index in the molecular plane. As a result of averaging over possible molecular orientations the material has optical characteristics similar

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† http://www.optivainc.com

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to discotic LCs. For these reasons we schematically represent the structure of this phase as a discotic phase; however, the detailed nature of the structure of this phase remains unknown. This general structure has been confirmed by the studies described here and independently by others [9, 10]. At a concentration above 5 wt% the aqueous dye solutions form the nematic phase with high ordering of the director that is perpendicular to molecular plane. For certain processing conditions, ordered films can be formed. Ordered films of the dye can be produced from the nematic lyotropic phase by shearing on a glass or plastic substrate using a blade applicator or a wire-wound rod applicator. We applied the dye mixture to clean glass substrates using two types of stainless rods from Gardner Co.: one wound with wire of 0.003 inch diameter and one without wire. Orientation of the dry films on the substrates was produced by shear flow of the nematic mixture and subsequent drying. The dried films consisted of oriented molecular layers forming an almost colourless birefringent medium.

The birefringence of the dried films was measured using the null ellipsometry technique. The measurement method is a transmission ellipsometry (polarimetry) technique featuring a polarizer and a quartz wave compensation plate fixed at 45° with respect to horizontal direction, and a rotating analyser that should be initially crossed with the polarization incident on the sample [11]. The sample is mounted between the polarizer and the quarter wave plate with the shearing direction at 45° to the transmission direction of the polarizer. This configuration provides measurements of the phase shift between the two eigenpolarizations of the film. The light from a He-Ne laser propagating through the polarizer becomes linearly polarized at 45° with respect to the horizontal direction. The sample converts the polarization from linear to elliptical. The polarization is further transformed into almost linear polarization by the quarter wave plate. The direction of polarization of the light coming out of the quarter wave plate depends on phase shift between the two eigenpolarizations of the sample. This is determined by rotation of the analyser to the position of minimum light leakage. In the case of normal light incidence the angle of the rotation of the analyzer φ is connected to the in-plane retardation of the sample $(n_y - n_x)d$ by the relationship $(n_y - n_x)d = \lambda_{\varphi}/180$, where d is the thickness of the sample, and n_x and n_y are two principal refractive indices for the light polarized in horizontal and vertical directions, respectively. In the case of oblique light incidence (obtained by rotating the sample about a vertical axis) the phase shift is calculated numerically from Maxwell's equations for light propagation in a biaxial medium using Berreman's 4×4 matrix method [12].

Figure 1 shows the measured curves for the phase shift φ versus the incidence angle of the testing beam θ for two orthogonal azimuths for the shearing direction of the lyotropic film: 1-horizontal and 2-vertical. The symmetry of the curves confirms that the three principal axes of the dielectric tensor coincide with a Cartesian frame with two axes (x and y) in the film plane and one axis coincident with the shearing direction (the y-axis). Curve fitting, assuming the most general case of optical biaxiality, revealed the following relationship between the three principal indices of refraction: $n_y = n_e < n_x = n_z = n_o$ and $(n_o - n_e)d = 27$ nm. The higher in-plane refractive index appears in the direction perpendicular to the shearing. The film is negative and uniaxial with and the optic axis along the shearing direction. This relationship suggests, that the molecules form the structure shown in figure 2. The value of the film's birefringence was found to depend on the concentration of water in the initial mixture and the thickness of the lyotropic layer.

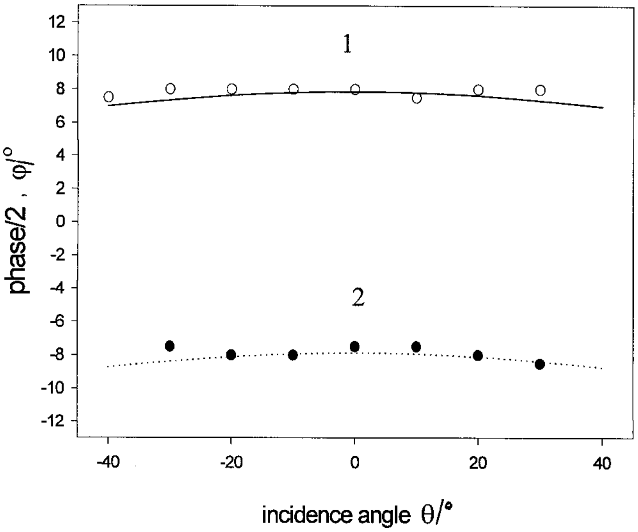

Figure 1. Ellipsometry results for the optical phase shift versus incidence angle for two orthogonal azimuths for the shear direction of the lyotropic film.

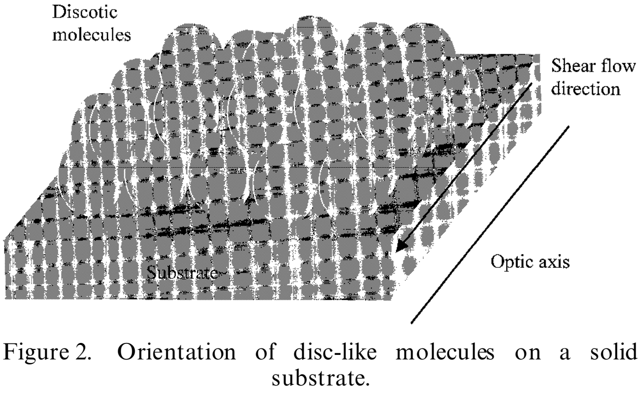

Figure 2. Orientation of disc-like molecules on a solid substrate.

3. Application of the negative birefringence film to the improvement of the optical performance of a twisted nematic cell

A twisted nematic (TN) device operating in the normally white mode has a 90° twisted LC cell placed between two crossed polarizers. With no voltage applied to the cell, the device appears bright, as it provides almost complete rotation of polarization for the light within the visible spectrum. The application of a voltage well above the Fréedericksz threshold reorients the LC molecules to the almost homeotropic state with splayed director distribution near the substrates. The device in the activated state appears dark only for near head-on viewing. Negative birefringence films introduced by Fuji Co., combined with negative C-plates, can compensate the homeotropic and splayed layers of the positive liquid crystal for light incident off-normal. The Fuji film features the tilt angles of the optic axis, from 90° near the film's substrate to 30° near the free surface that faces the liquid crystal cell and a negative C-plate as a substrate. The films should be placed on both sides of the LC cell in order to mirror the LC director. Because of the high tilt angle of 30° near the free surface the Fuji film does not provide full compensation of the almost planar LC layers close to the alignment layers.

In a previous publication [5] we showed that negative A-plates with a small retardation value of $(n_o - n_e)d =$ 25–35 nm can compensate the LC planar layers to improve the dark state of a TN display when combined with the compensation films introduced by Fuji Co. In this work we used the lyotropic film (negative A-plate) with the in-plane retardation of 25 nm as an intermediate layer between the Fuji film and the LC cell on both sides of the TN device (figure 3). Figure 4 shows the viewing angle characteristics for a device built with this display configuration. The active element of the device was a TN cell, a thickness 4.8 μm, filled with the liquid crystal mixture ZLI-4792 (Merck); it was driven between 0 and 6 V corresponding to the bright and dark states, respectively, of the device. In the contour plot, the radius represents the polar viewing angle with the origin being for on-axis viewing and the perimeter corresponding to 60° off-axis; the azimuthal angle corresponds to the azimuthal viewing angle. Azimuthal angles of 0° and 180° correspond to viewing from the right and left sides of the device, respectively, and the azimuthal angles of 90° and 270° to the up and down directions, respectively. The numerical value of each contour is the ratio between the transmitted luminance of the bright and the dark states measured in white light. The display with negative A-plates possesses higher contrast ratio at all viewing directions compared with the similar device that is compensated with Fuji films only, without the additional in-plane negative retarders (figure 5). This compensation method provides a contrast ratio of 30:1 at the polar angle of 45° for horizontal viewing, which meets the requirements for high quality wide panel liquid crystal displays.

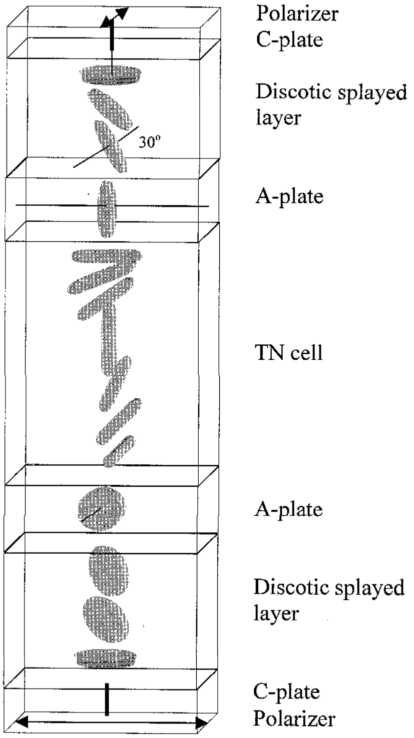

Figure 3. Configuration of a twisted nematic device compensated with negative C-plates, splayed discotic films and negative A-plates.

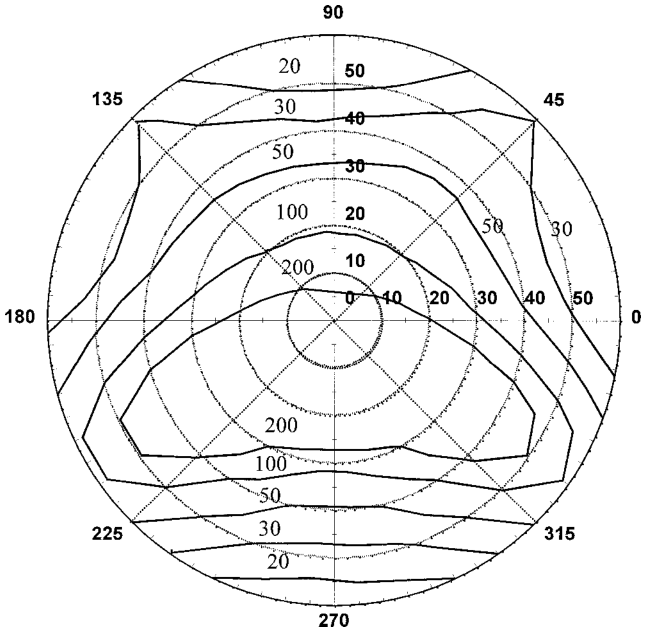

Figure 4. Measured isocontrast curves for a TN cell compensated with lyotropic films and Fuji films. The cell was driven between 0 and 6 V.

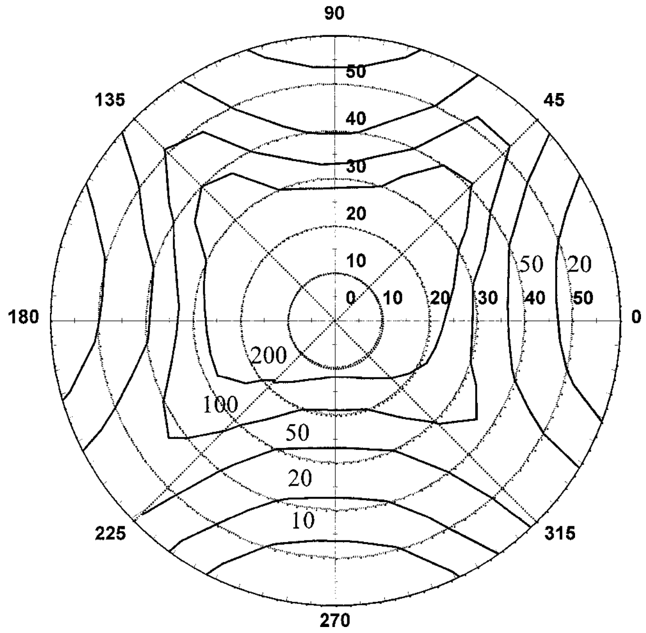

Figure 5. Measured isocontrast curves for a TN cell compensated with Fuji films only. The cell was driven between 0 and 6 V.

4. Conclusions

We studied the oriented molecular layers formed from a lyotropic liquid crystal by shear flow. The layers form negative birefringence films with the optic axis oriented along the shearing direction of the material, and variable retardation values depending on the film thickness and concentration of water in the initial mixture. We used the dried lyotropic layers for compensation of the dark state of the twisted nematic liquid crystal device, combined them with commercially available optical retarders. The proposed compensation configuration greatly improves the viewing angle performance of the normally white TN device. Ease of fabrication and the range of retardation that can be achieved in these films make them ideal for high volume manufacture of negative A-plates for a range of compensation applications.

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